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EFFECT OF WING MODIFICATIONS ON THE LONGITUDINAL STABILITY OF A TAILLESS ALL-WING AIRPLANE MODEL

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ADVANCE CONFIDENTIAL REPORT

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SUMMARY

An investigation of the power-off longitudinal stability characteristics of a tailless all-wing airplane model with various wing modifications has been made in the Langley free-flight tunnel. Force and tuft tests were made on the model in the original condition, with the wing tips rotated for washout, with rectangular and swept-forward tips, and with various slat arrangements. Flight tests were made with the original wing and with the original wing equipped with the most promising modifications.

The results indicated that changes in tip plan form or rotation of the wing tips did not appreciably reduce the instability at high lift coefficients. Addition of wing slats, however, improved the longitudinal stability at the stall when the slat extended far enough inboard to cover the area that tended to stall first.

INTRODUCTION

Sweepback is often incorporated in the design of tailless airplanes in order that high-lift flaps may be used on the center sections of the wing to increase the over-all maximum trim lift coefficient of the airplane. (See reference 1.) Quite often, however, the sweepback defeats its own purpose by causing premature tip stalling and longitudinal instability at high angles of attack and thus making it impossible for the airplane to attain its maximum lift coefficient in flight. A model of a tailless all-wing airplane with sweepback and taper recently tested in the Langley free-flight tunnel (reference 2) showed this tendency. The maximum trim lift coefficient

[redacted]

of this model with flaps retracted, as measured by force tests, was about 1.2; but because of the poor stability and control near the stall the highest lift coefficient at which it could be flown was 0.7.

In an attempt to improve the longitudinal stability characteristics of swept-back all-wing tailless airplanes, an investigation of various means of preventing tip stall has been made in the Langley free-flight tunnel. The model used in the tests of reference 2 was also used for the present investigation. The test program included force and tuft tests, power off, of the original wing, of the original wing with the wing tips rotated for wash-out, of the wing with modified rectangular and swept-forward wing tips, and of the original wing with four slat arrangements. Flight tests were made with the original wing and with the original wing equipped with the most promising modifications.

SYMBOLS

L lift, pounds

M pitching moment, foot-pounds

N yawing moment, pounds

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

C_m pitching-moment coefficient about $0.20\bar{c}$ $\left(\frac{\text{Pitching moment}}{q\bar{c}S}\right)$

C_D drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$

S wing area, square feet

R Reynolds number

c wing chord, feet

$\bar{c}$ mean aerodynamic chord, feet

[redacted]

b	wing semispan, feet
V	airspeed, feet per second
α	angle of attack, degrees
ψ	angle of yaw, degrees
β	angle of sideslip, degrees
ϕ	angle of bank, degrees
θ	rotation of wing tip, degrees
δ_e	elevon deflection, degrees
δ_r	rudder deflection, degrees
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ρ	mass density of air, slugs per cubic foot

APPARATUS

The tests were conducted in the Langley free-flight tunnel, which is described in reference 3. A photograph of the test section of the tunnel showing the model in flight is presented as figure 1.

Force tests made to determine the static stability characteristics of the model were made on the Langley free-flight tunnel six-component balance. (For a description of the balance see reference 4.) All forces and moments measured on this balance are taken with respect to the stability axes, which are shown in figure 2.

The model is the one that was used in the tests reported in reference 2. The model is of a tailless all-wing airplane having an aspect ratio of 7.36, a taper ratio (ratio of tip chord to root chord) of 0.25, and sweepback of the quarter-chord line of 22°. A three-view drawing of the model is presented as figure 3; and plan-view and three-quarter front-view photographs are presented as figures 4 and 5, respectively. For the present tests, the wing tips were cut at the outboard end of the elevons and altered so that the angle of incidence of the tips could be changed or the tips removed entirely. (See fig. 6.) Two additional sets of tips extending 28 percent of the wing semispan - one rectangular and one with 5° sweepforward of the quarter-chord line - were built to fit the wing where the original tips were cut. Leading-edge slats for the outer part of the span were constructed in three sections, any of which could be attached to the wing separately.

The model tested in the Langley free-flight tunnel (designated FFT) at low Reynolds numbers was, in its original condition, identical in plan form to a model that was tested in the Langley 19-foot pressure tunnel (designated 19-ft PT) at high Reynolds numbers; data for the tests in the Langley 19-foot pressure tunnel are given in the present paper for comparison with the results of tests in the Langley free-flight tunnel. The two models, however, differed in airfoil section and number of propeller-shaft housings. The model tested in the Langley 19-foot pressure tunnel had an NACA 65(318)-019 airfoil section at the root and NACA 65(318)-015 section at the tip; and the model tested in the Langley free-flight tunnel had a modified NACA 103 airfoil section with a thickness of 21 percent chord at the root and 15 percent chord at the tip. The aerodynamic washout for both models was approximately 4°.

TESTS

Force tests were made to determine the static stability characteristics of the model in each of the test conditions. The force-test data for each arrangement were based on the area and the mean aerodynamic chord of the particular wing plan form tested.

Tuft studies were made of each model configuration to determine the stalling characteristics of the wing. For these tests, the model was mounted on the balance strut.

Force and tuft tests were run at a dynamic pressure of 4.09 pounds per square foot, which corresponds to a test Reynolds number of about 240,000 based on a mean aerodynamic chord of 0.655 foot. All force and tuft tests were made with flaps retracted, vertical fins off, and the elevon and rudder control surfaces set at 0°.

Flight tests were made with combinations of slats 1 and 2 and 1, 2, and 3. (See fig. 6.) These tests were made with the center of gravity at 20 percent of the mean aerodynamic chord and over a range of lift coefficients from 0.5 to 1.0. All flight tests were made with flaps retracted and with vertical fins installed. These fins were added to improve the directional stability; previous tests have indicated that they had no effect on longitudinal stability.

All tests were made with power off and propellers removed.

RESULTS AND DISCUSSION

In interpreting the results of the tests made in the Langley free-flight tunnel, the following points should be considered:

(1) The tests were made at very low Reynolds numbers (150,000 to 350,000).

(2) The controls of the model during the flight tests were fixed except during control applications; hence, no indication of the effect of the modifications on the control-free stability of the design was obtained.

Results of the force tests are shown in figure 7. In figure 8, the curves of pitching-moment coefficient against lift coefficient are replotted to compare the stability characteristics for the various wing modifications. Data for the model of similar plan form tested at high Reynolds numbers in the Langley 19-foot pressure tunnel are also shown in figures 7 and 8. Results of tuft surveys in the Langley free-flight and 19-foot pressure tunnels are presented in figure 9.

Original Wing

The force-test data of figure 8(a) and the tuft-test data of figure 9(a) illustrate the usual effect of sweepback and taper upon the static longitudinal stability and the stalling characteristics of a wing. These data show that the premature stalling over the elevons near the wing tip caused the original wing to become neutrally stable at a lift coefficient of about 0.90.

The data of figures 7 and 8(h) also show that at high lift coefficients the longitudinal instability of the free-flight-tunnel model, tested at low Reynolds numbers, was greater than that of the pressure-tunnel model, tested at high Reynolds numbers. The results of the force tests made in the Langley free-flight tunnel are believed to be conservative in that the necessary improvement in longitudinal stability at high Reynolds numbers is less than the improvement indicated by the tests at low Reynolds numbers. It is interesting to note, however, that in contrast to the dissimilarity of the pitching-moment curves for the free-flight-tunnel model and the pressure-tunnel model (fig. 8(h)), the stalling characteristics as indicated by tuft surveys are quite similar for the two models (figs. 9(a) and 9(i)). When flown, the model showed a tendency to nose-up and stall after disturbances in pitch at a lift coefficient of about 0.65, and it was not possible to fly the model at lift coefficients above 0.7. (See reference 2.)

Effect of Wing-Tip Modifications

A comparison of the curves in figure 8(a) shows that rotating the wing tips -10° had little effect on the longitudinal stability and did not prevent instability at the stall. The tuft-survey results in figures 9(a) and 9(b) show that, although the stalling of the tip was improved slightly by deflecting the tip, the stall inboard of the tip was relatively unaffected. Correlation of these results with force-test results indicates that an improvement of the stall over the elevons as well as over the tips is necessary to eliminate the longitudinal instability at high angles of attack.

Force tests of the swept-forward and rectangular tips (figs. 8(b) and 8(c)) showed no improvement in the stalling characteristics.

Effect of Slats

Addition of various slat arrangements caused definite improvements in the longitudinal stability characteristics at the higher lift coefficients. This effect is shown in figures 8(d) to 8(g). The tuft tests showed that at high angles of attack the slat arrangements cleared the stalling on the tip in approximately direct proportion to the span of the slats, and the premature stalling over the elevons was improved only by the slat arrangements that extended in front of the elevons. (See figs. 9(e) to 9(h).) The slight roughness and stalling within the span of combinations of slats 1 and 2 and 1, 2, and 3 is attributed to slat supports, which are located between the individual slats.

With the 50.5-percent-semispan slat and the 70.5-percent-semispan slat installed, the model could be flown to a maximum lift coefficient of 1.0 - an increase of 0.3 over the maximum lift coefficient with the original wing - and did not show the nosing-up tendency noted in flight tests of the original wing.

CONCLUSIONS

The following conclusions were drawn from tests of a tailless all-wing airplane model with various wing modifications in the Langley free-flight tunnel:

1. Changes in wing-tip plan form over the outer 28 percent of the wing semispan caused no appreciable improvement in longitudinal stability at the stall.

2. Decreasing the angle of incidence of the wing tip (28 percent of the wing semispan) by 10° had little effect on the longitudinal stability and did not prevent longitudinal instability at the stall.

3. The use of partial-span wing slats eliminated the longitudinal instability at the stall when the slat span

was great enough to extend inboard in front of the part of the wing that tended to stall first.

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REFERENCES

1. Pitkin, Marvin, and Maggin, Bernard: Analysis of Factors Affecting Net Lift Increment Attainable with Trailing-Edge Split Flaps on Tailless Airplanes. NACA ARR No. L4I18, 1944.

2. Campbell, John P., and Seacord, Charles L., Jr.: Determination of the Stability and Control Characteristics of a Tailless All-Wing Airplane Model with Sweepback in the Langley Free-Flight Tunnel. NACA ACR No. L5A13, 1945.

3. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN No. 810, 1941.

4. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of the Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR No. 3D17, 1943.

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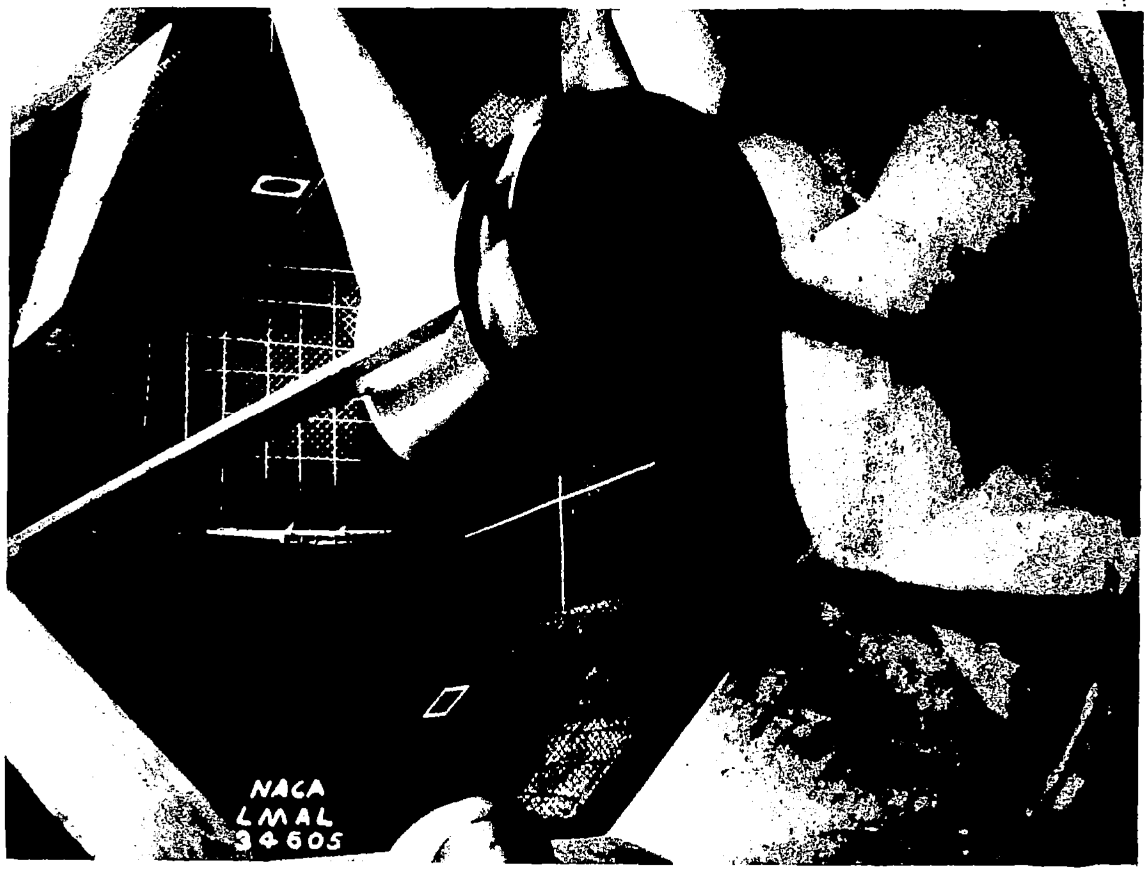

Figure 1.- Test section of Langley free-flight tunnel with model in flight.

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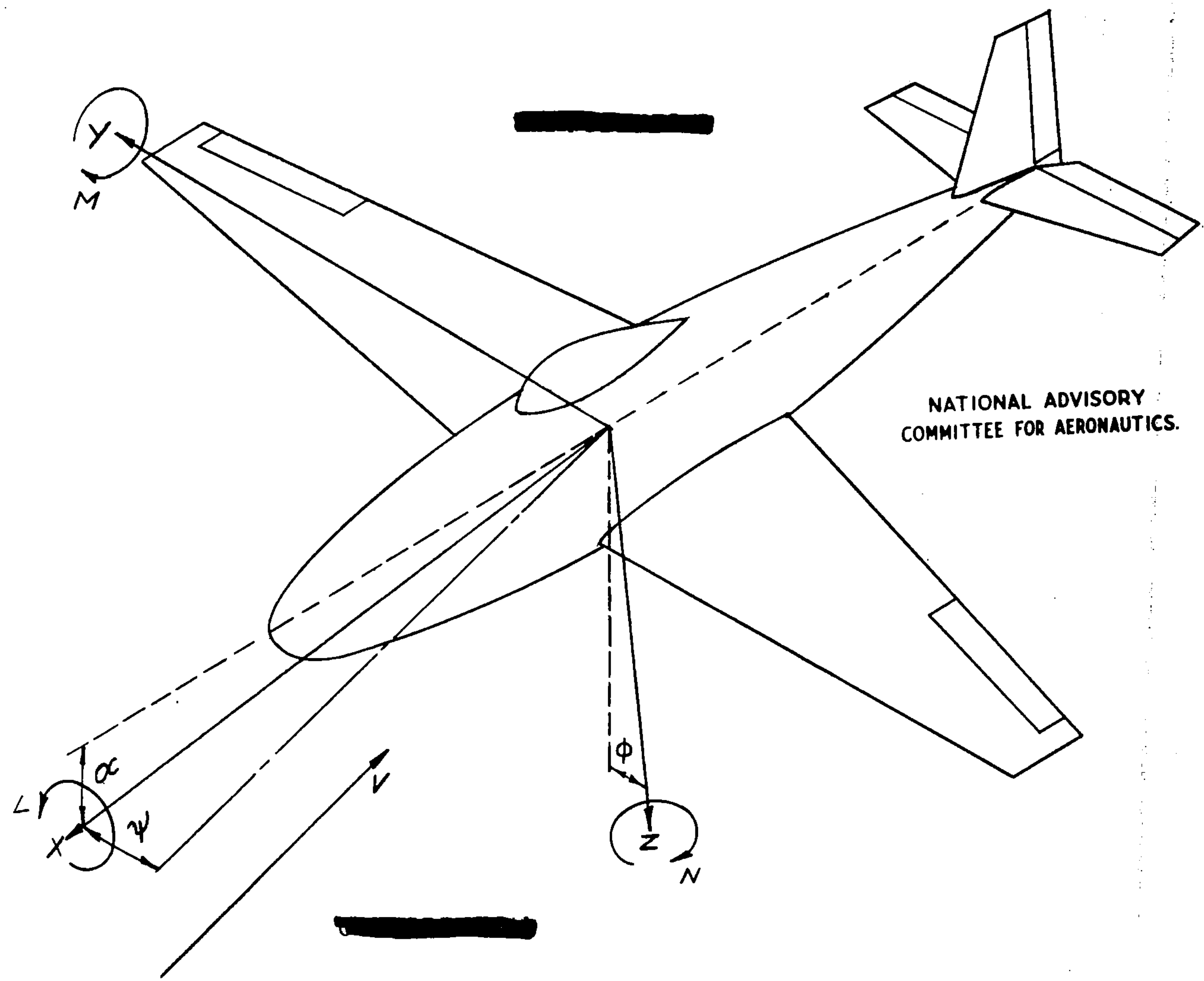

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Figure 2.- System of stability axes. Arrows indicate positive direction of moments and forces.

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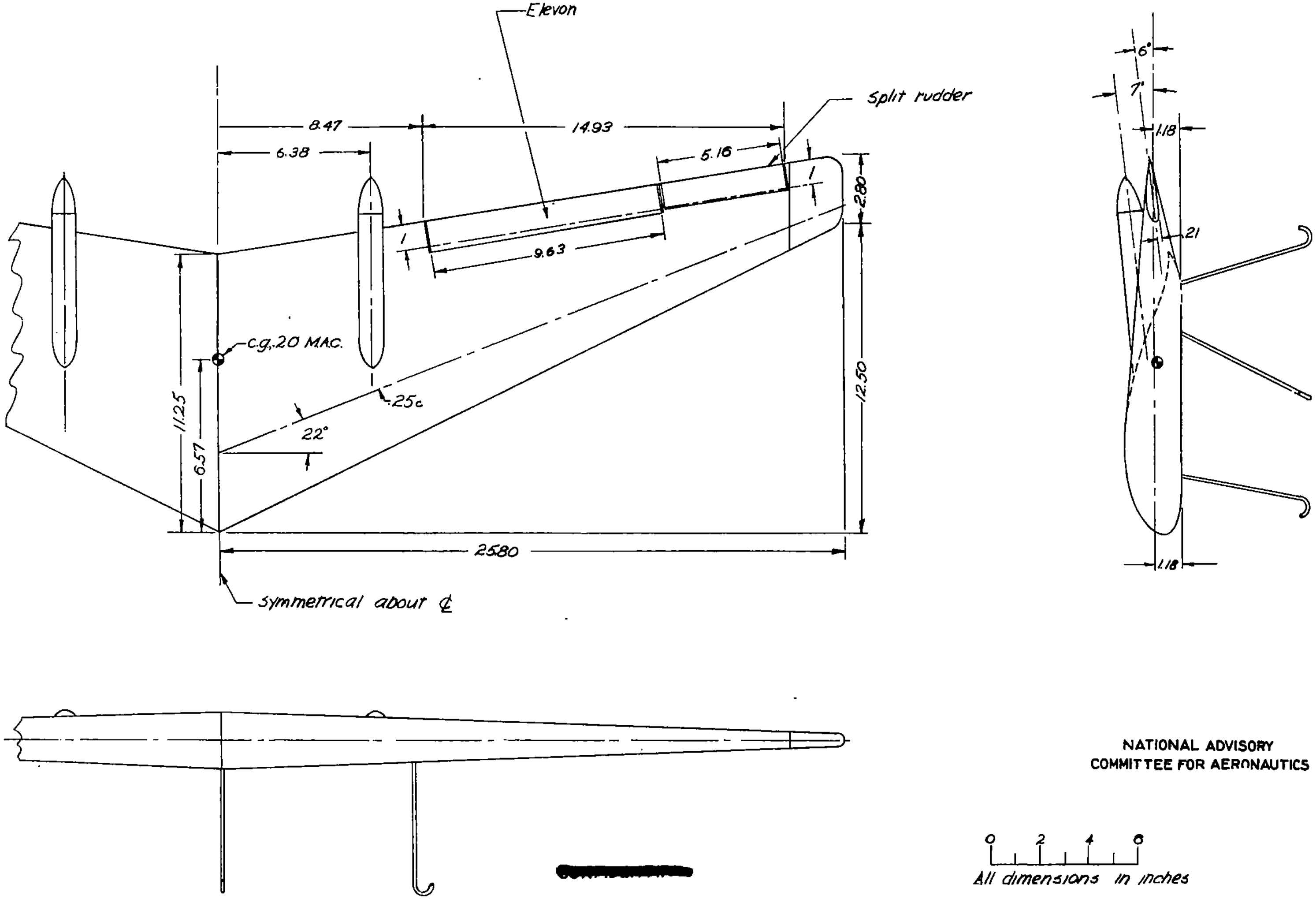

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Figure 3.- Tailless airplane model tested in the Langley free-flight tunnel.

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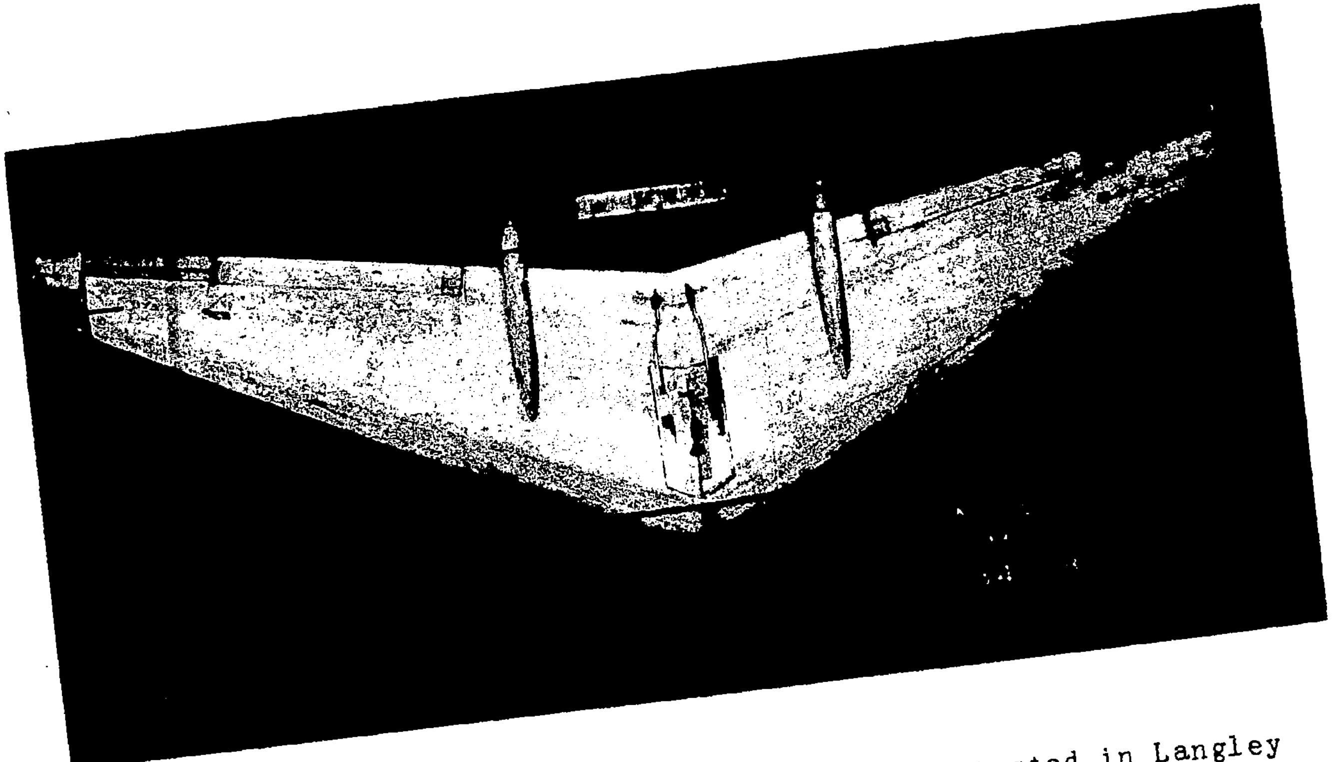

Figure 4.- Plan view of tailless airplane model tested in Langley free-flight tunnel.

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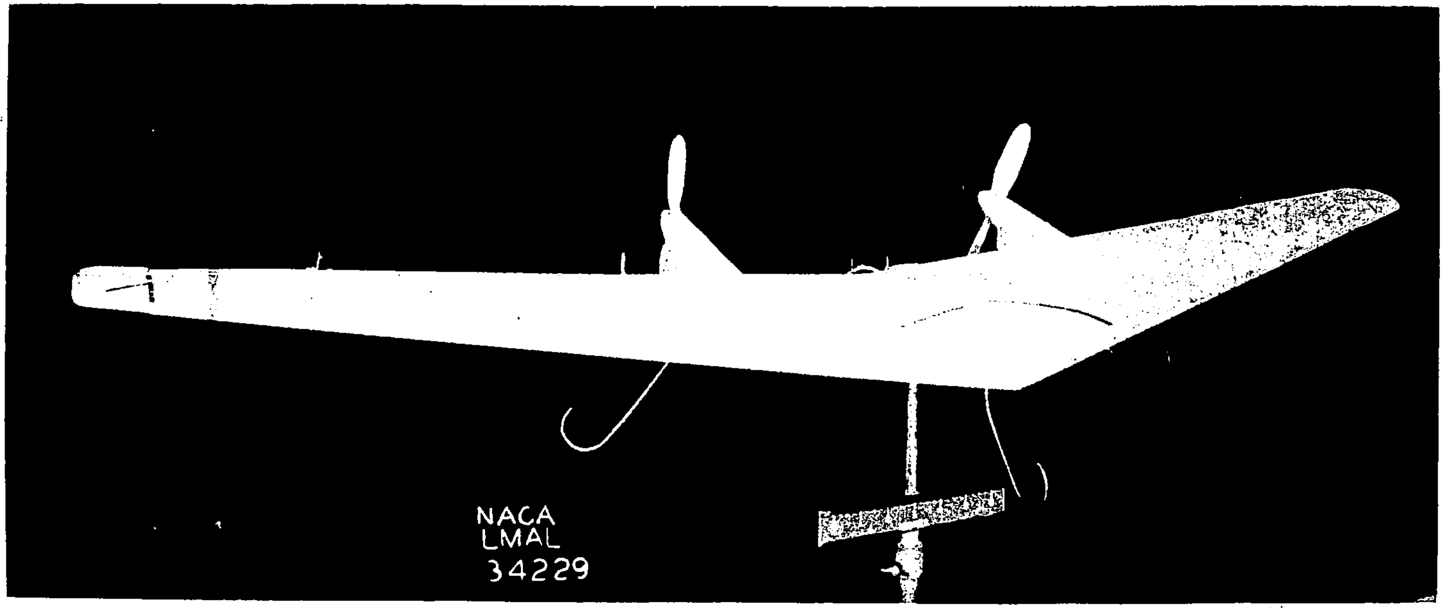

Figure 5.- Three-quarter front view of tailless airplane model tested in Langley free-flight tunnel.

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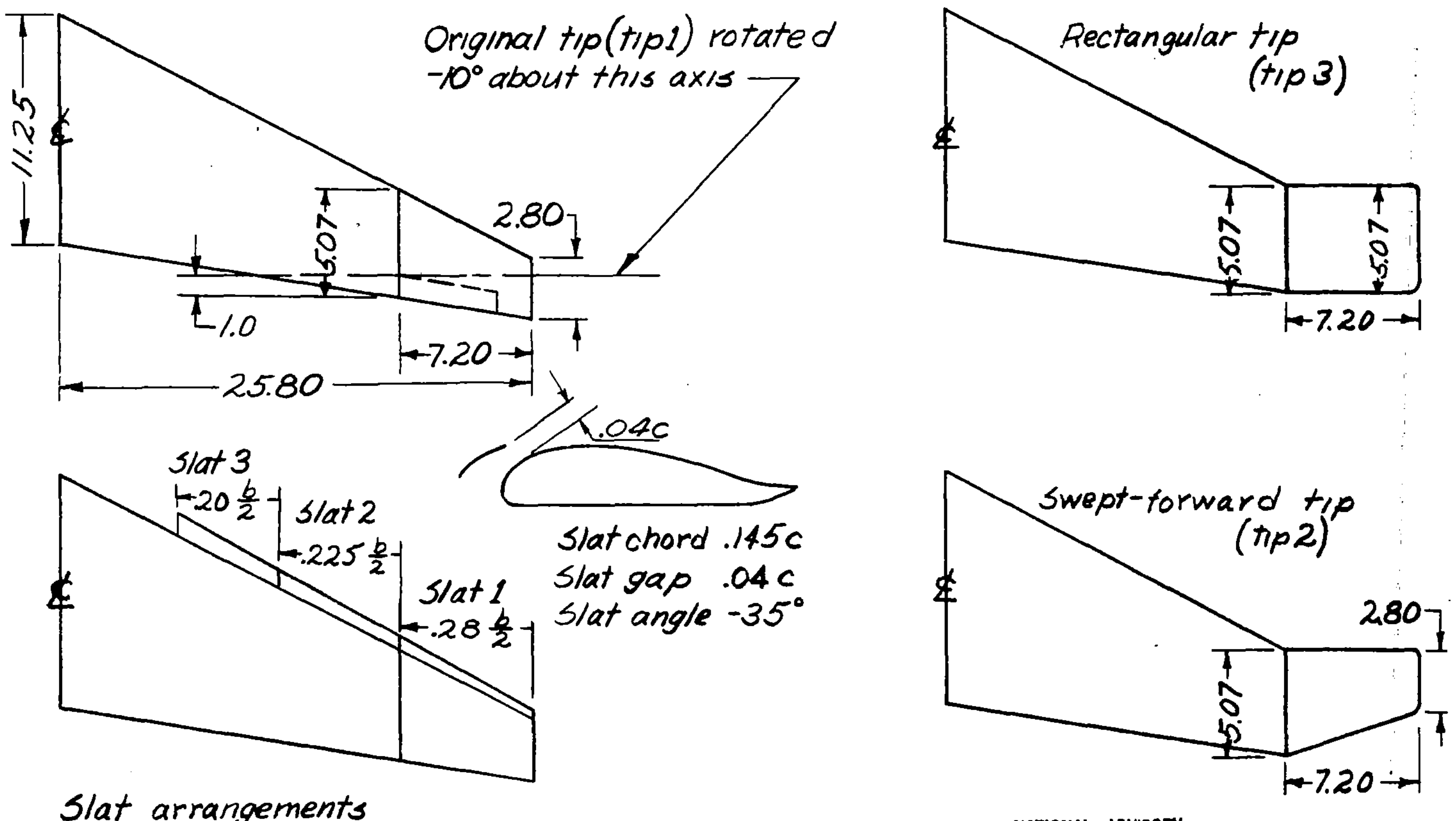

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Figure 6.- Wing modifications on the tailless airplane model tested in the Langley free-flight tunnel. (All dimensions in in.)

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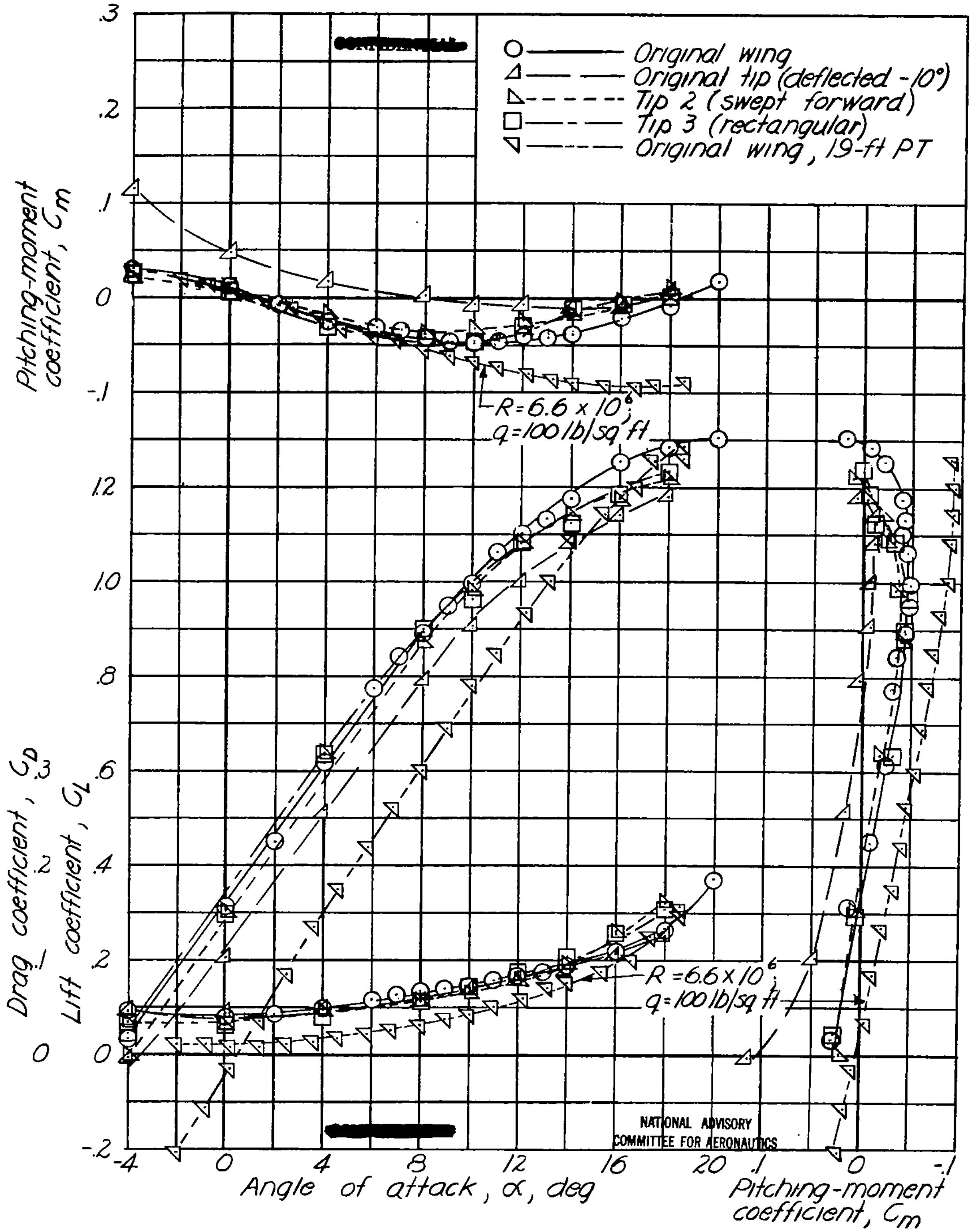

Figure 7.- Aerodynamic characteristics of Langley free-flight-tunnel tailless airplane model with various wing modifications. $\delta_e = \delta_r = 0°$; flaps retracted; center-of-gravity location, 0.20 M.A.C.; $q = 4.09$ pounds per square foot except as noted.

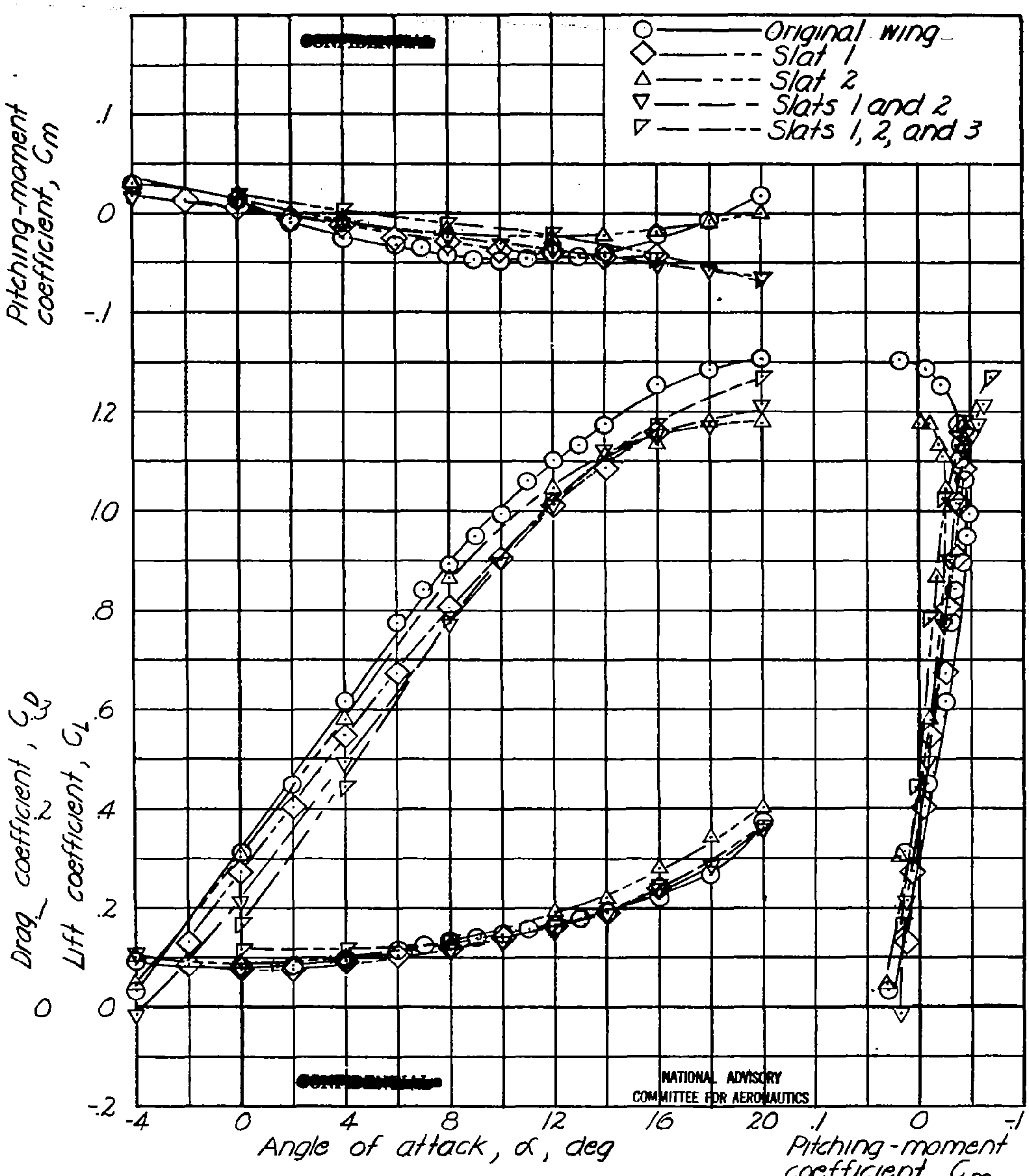

Figure 7.- Concluded.

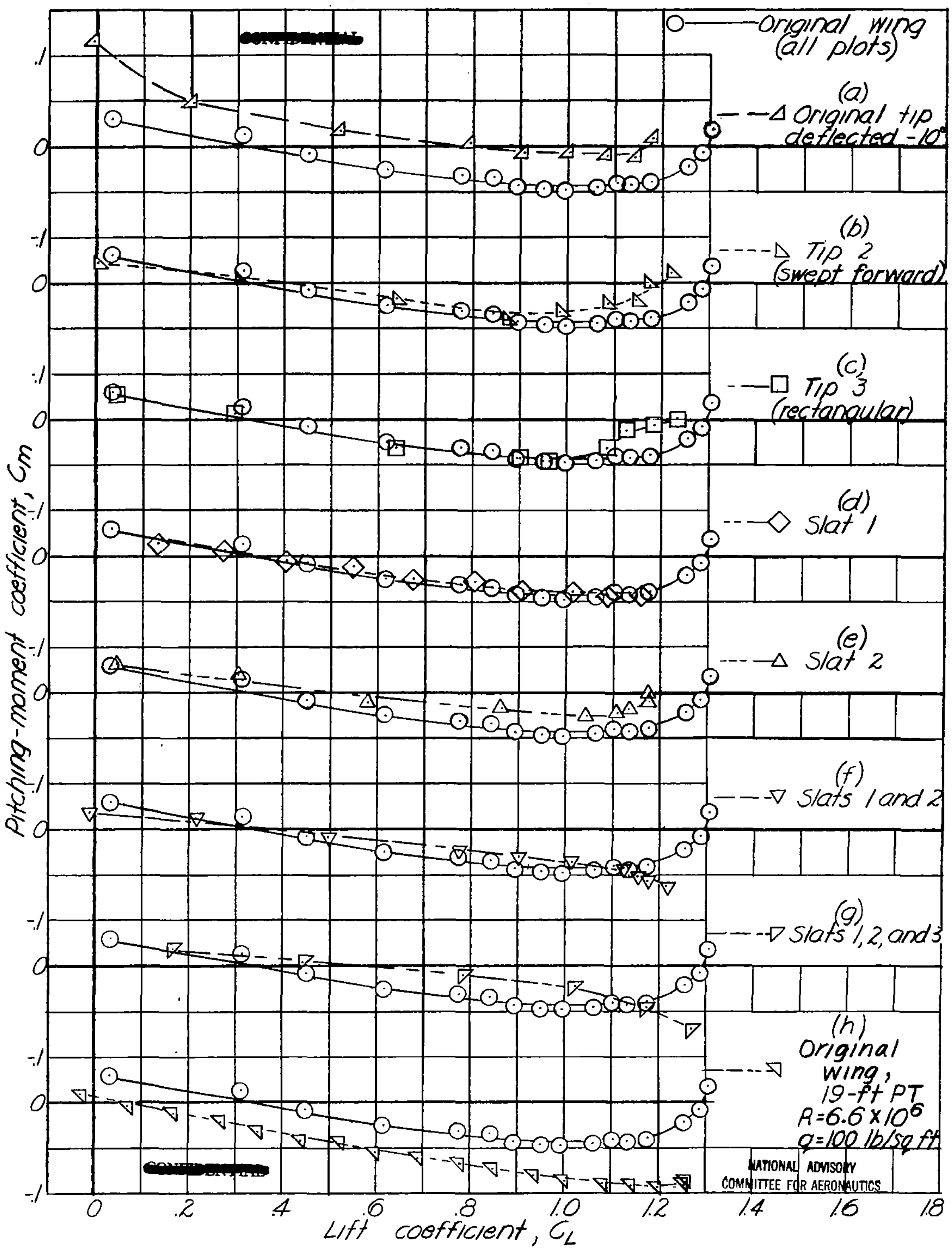

Figure 8.- Pitching-moment characteristics of Langley free-flight-tunnel tailless airplane model with various wing modifications. $\delta_e = \delta_r = 0°$; flaps retracted; center-of-gravity location, 0.20 M.A.C.; q = 4.09 pounds per square foot except as noted.

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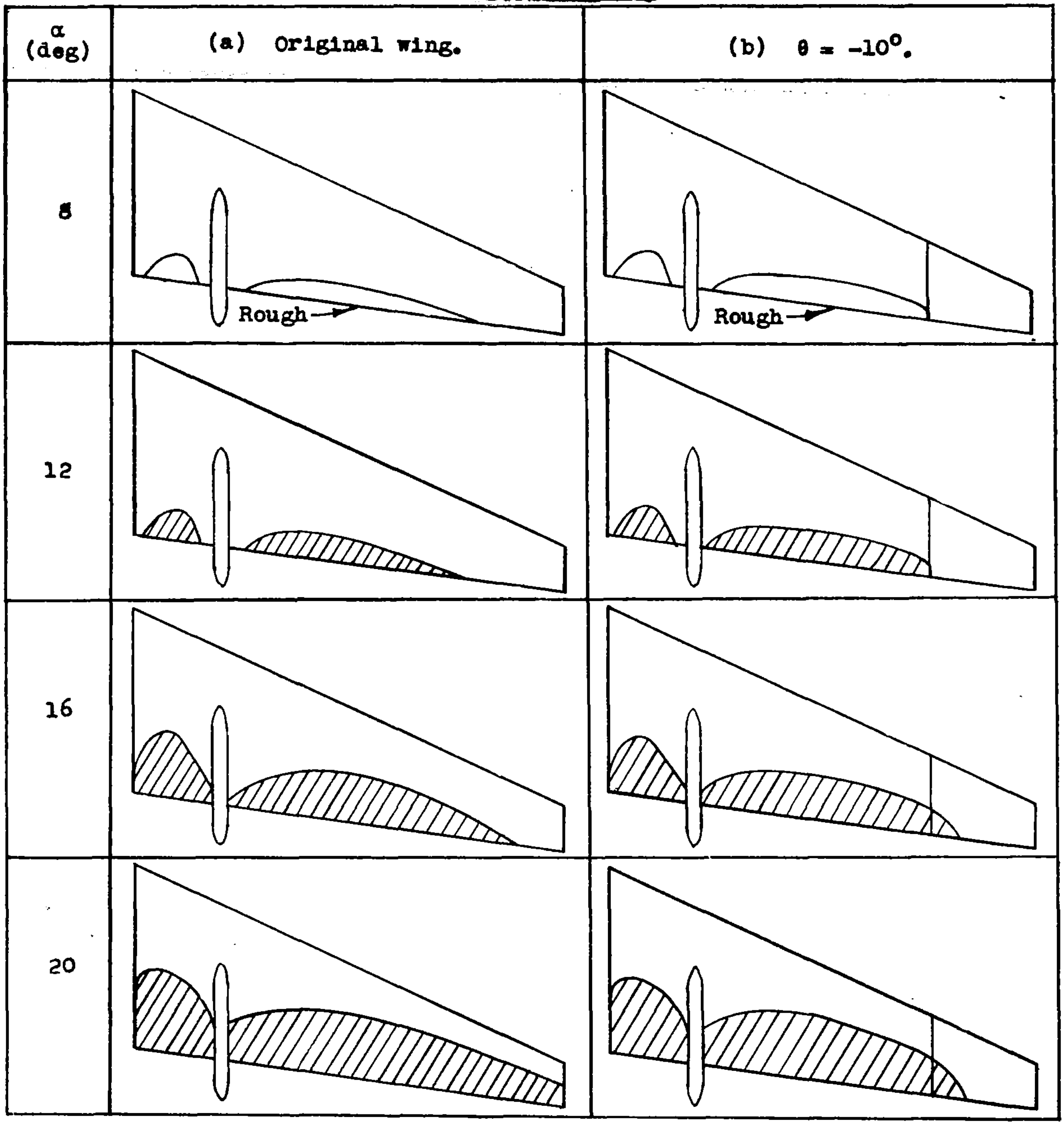

Figure 9.- Results of tuft surveys of tailless airplane model in Langley free-flight tunnel. $\delta_e = \delta_r = \beta = 0^\circ$; $q = 4.09$ pounds per square foot.

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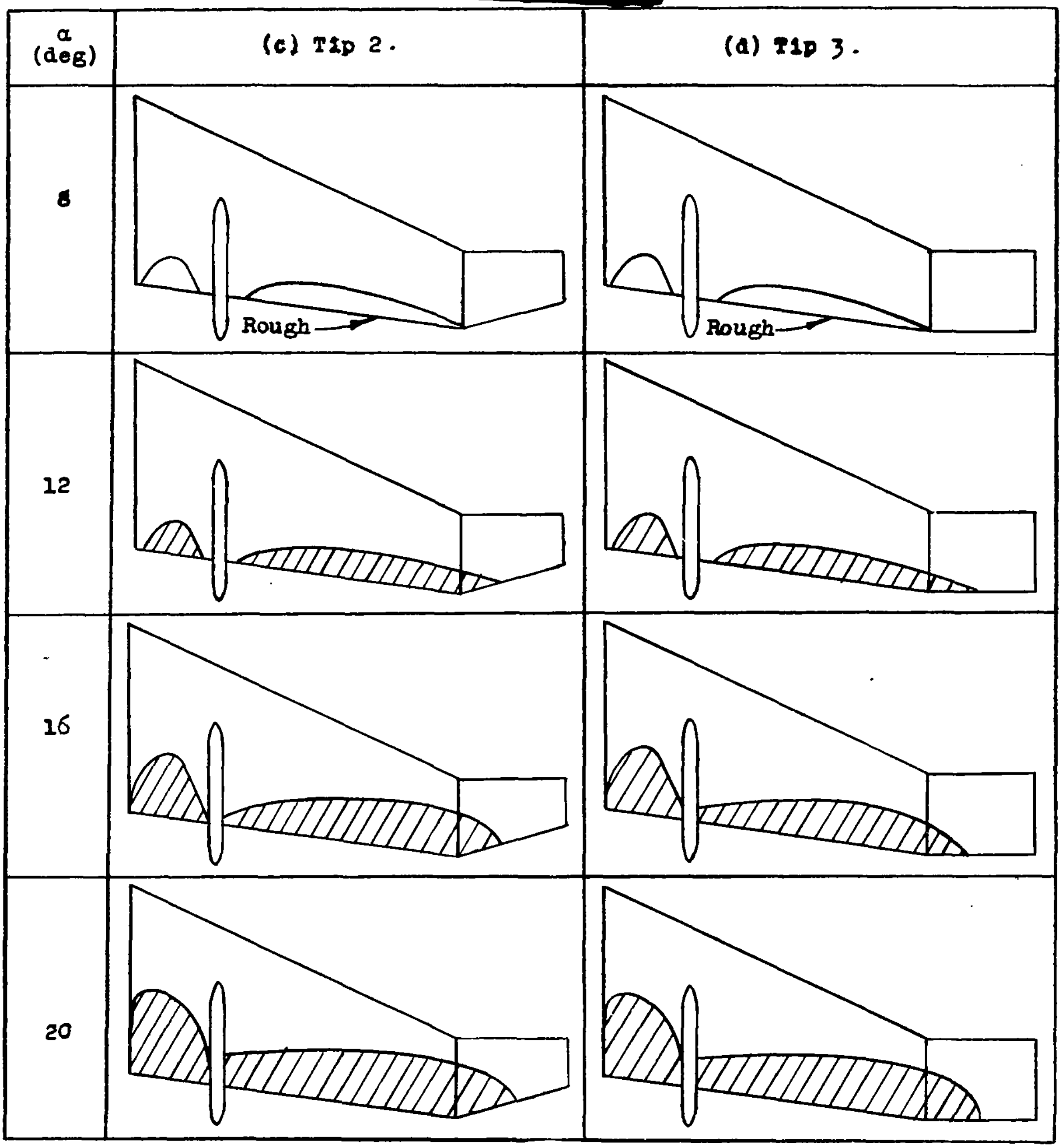

Figure 9.- Continued.

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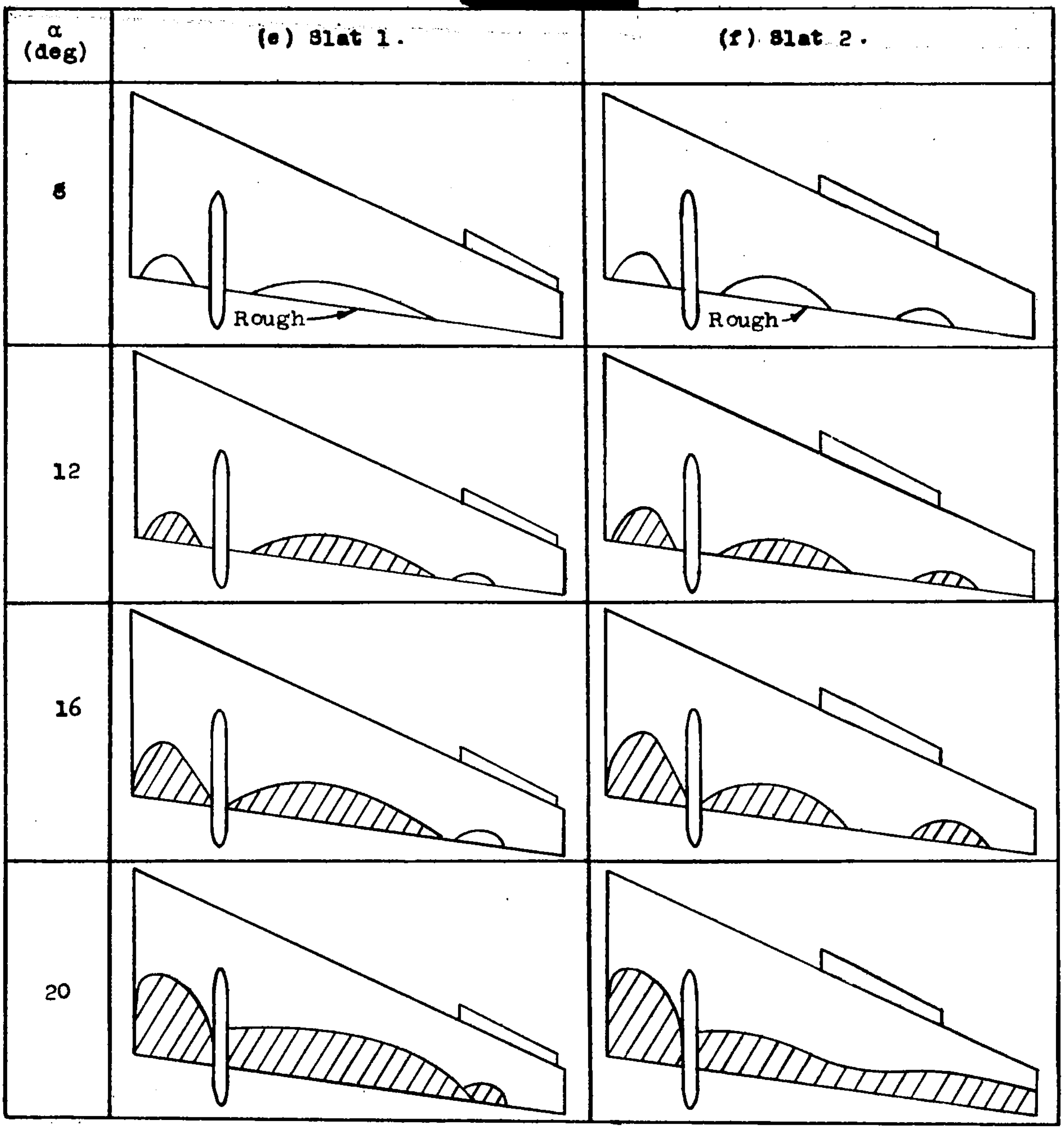

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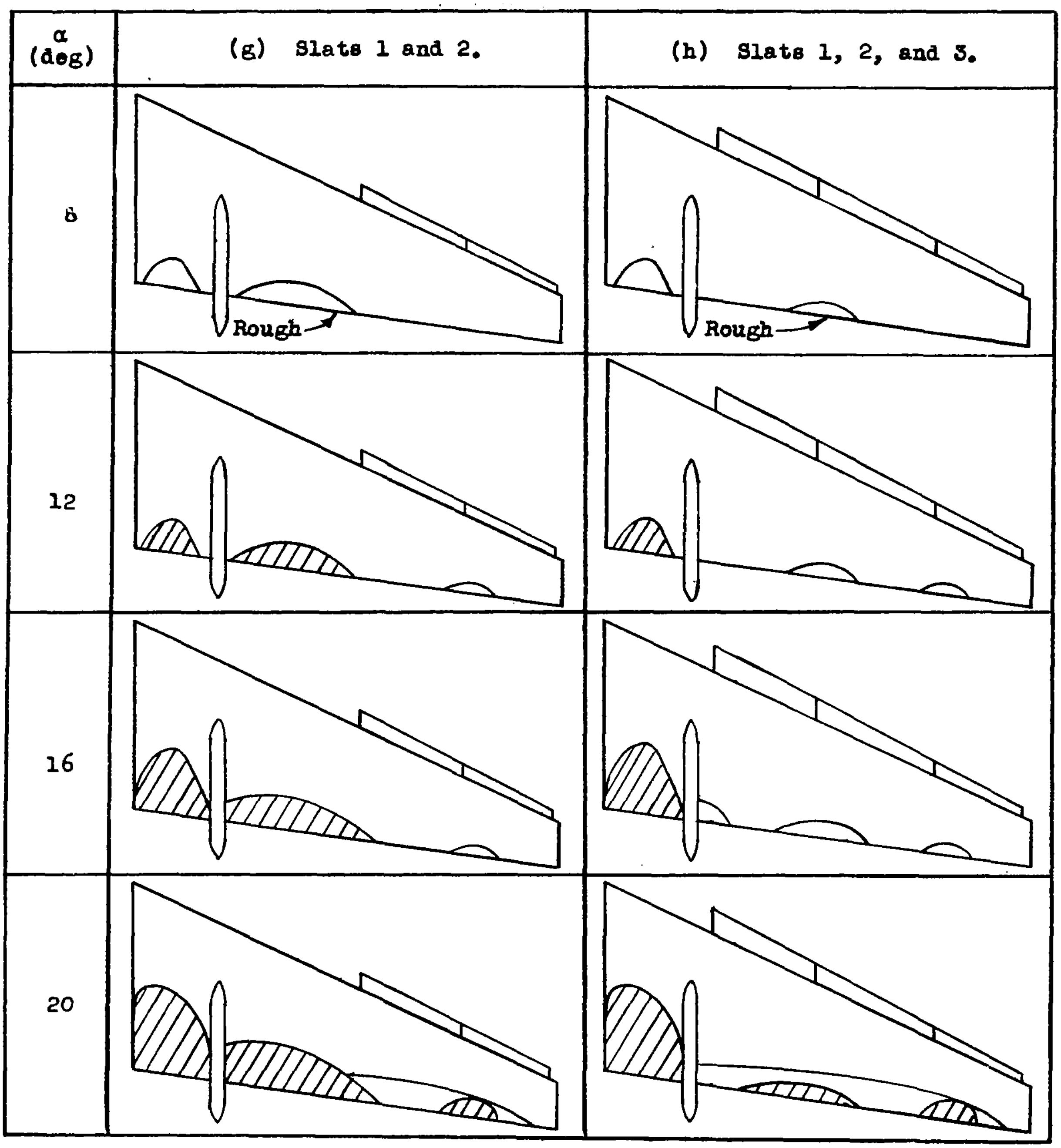

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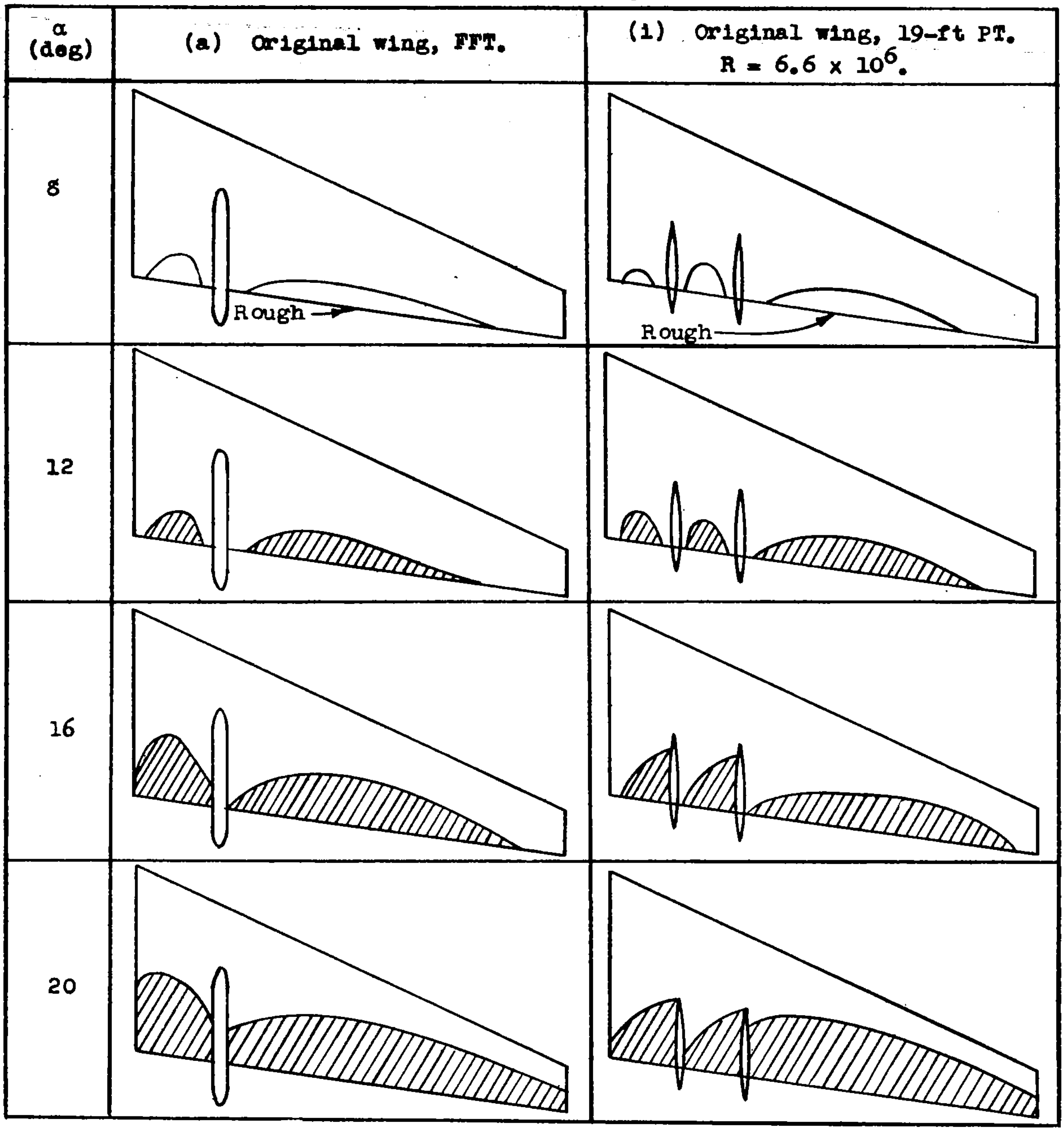

Figure 9.- Concluded.

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